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PHYSIOLOGICAL AND PERFORMANCE COMPONENTS OF ENDURANCE

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled PHYSIOLOGICAL AND PERFORMANCE COMPONENTS OF ENDURANCE submitted by D.J. SMITH in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Physical Education.

DEDICATION

To my late mother

7 . 8 . 80

ABSTRACT

In order to determine the physiological and performance indices of the different types of endurance, seventy university athletes representing five different sports and two mixed groups were tested. Factor analysis revealed three physiologically different types of endurance. Anaerobic endurance was identified by the performance of the 3rd repeat time of 80 m every 30 s. The laboratory variables which loaded highly on this factor were % $\dot{V}O_2$ max at AnT and maximal lactate concentration. Anaerobic-aerobic endurance was identified by the 6th repeat time for 80 m every 30 s. The laboratory variable which loaded highly was % $\dot{V}O_2$ max at AeT. Aerobic endurance was identified by 5000 m run time and $\dot{V}O_2$ max, $\dot{V}O_2$ at 180 $b{\cdot}min^{-1}$, speed at AeT, speed at AnT, and submaximal lactate concentration loaded highly on this factor. A repeated high-intensity endurance test was developed and may be used as a field test of anaerobic endurance and anaerobic-aerobic endurance. A physiological model, representing a continuum of endurance from short to prolonged duration exercise is proposed which may enable a meaningful interpretation of the cardiovascular responses to specific sporting activities.

PREFACE

> Most explorers are thought to be mad by someone,
> and all explorers are lonely.
>
> Wilder Penfield

My interest in understanding the physiological and performance components of athletes began in 1974 during my second year at St. Luke's College, Exeter, England, where Dr. P.R. Travers had developed a series of physiological tests, and was actively involved in evaluation of members of the British cycling and athletics team. Through his inspiration, my first training project was undertaken from January to March, 1975 with the help of Peter Hawkey and Dick Telford and other friends of mine who trained for me. The results of that study laid the foundations of my future training methods and athlete evaluation concepts.

After several other projects in the following years, I had my first glimpse at elite endurance athletes when I tested two marathon runners after the 1977 Commonwealth Games marathon trials. In an on-going study with Peter Moore which followed those tests, I was able to test, prescribe and monitor training, in his preparation for three world cross-country championships in Europe, and the Boston, New York and Seattle marathons. Further studies on endurance athletes were conducted with Craig Wronko for cycling and cross-country skiing and with Andrew Barron, in an 8 month case-study for cross-country skiing after his retirement as an Olympic and world championship speed skater. To these three athletes I owe a great debt, since without them, I would not have developed some understanding of the endurance athlete.

Through my advisors, Drs. Wenger and Quinney, I was able to undertake two projects, that allowed me to have some insight into another breed of athlete, the athlete involved in bursts of high-intensity activity. The testing and training prescription for the Canadian Olympic Ice-Hockey team, 1980, and the Edmonton Oilers Hockey Club presented a different challenge compared to the endurance athlete. However, it sparked the idea of a continuum of endurance. Further work with James Kendrick, a national junior judo team member has added to my interest and understanding of this type of athlete.

I hope that this small contribution to the area of exercise physiology will permit a meaningful understanding of performance and aid athletes in their pursuit of excellence.

ACKNOWLEDGMENTS

Special thanks to Dr. H.A. Wenger and Dr. H.A. Quinney for serving as co-chairmen of my doctoral committee for the last year of my Ph.D. programme. Thanks is extended to Dr. J.D. MacDougall of MacMaster University for serving as the external examiner. Special thanks are extended to Dr. A.E. Wall, Dr. R.G. Glassford and Dr. M.F.R. Smith for their support and interest in this study.

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INTRODUCTION

Man's ability to perform prolonged physical work has inspired many individuals to train for and participate in endurance activities such as long distance canoe events, cycle tours, marathon running and even 50 and 100 mile road races. These feats of athletic prowess have come under the scrutiny of exercise physiologists in an attempt to characterize, explain, and develop superior athletic performances. Many physiological variables have been studied from oxygen uptake and body composition to muscle fibre typing and enzymatic activity characteristics of a wide variety of sporting populations.

Maximal oxygen uptake ($\dot{V}O_2$ max) has been used as the major criterion of endurance performance, since among heterogeneous samples of distance runners, success has been found to depend largely upon $\dot{V}O_2$ max (Foster et al. 1978). However, when more homogeneous samples have been used this relationship has diminished (Costill et al. 1971). Davies and Thompson (1979) suggested that for a group of elite athletes, all of whom have a well developed $\dot{V}O_2$ max, the difference in performance may rest on the ability to utilize and sustain their aerobic capacity within very narrow limits. Furthermore, although a high $\dot{V}O_2$ max appears to be a prerequisite for successful endurance performance, prediction of performance may be influenced by other factors not reflected in $\dot{V}O_2$ max per se.

In some studies, increases in $\dot{V}O_2$ max have not occurred as a result of endurance training, yet improvements in performances have been documented (Daniels et al. 1978; Sprynarova et al. 1980). Induced cellular changes have been suggested to increase the capacity for submaximal work (Saltin and Rowell, 1980) and successful endurance athletes

have been characterized as being able to maintain high intensities of exercise with little accumulation of lactic acid in the plasma (Costill et al. 1971).

The measurement of anaerobic threshold (AT), as defined by Wasserman et al. (1973) and expressed in both relative terms (% $\dot{V}O_2$ max) (Davis et al. 1979) and absolute terms (speed or work rate at AT) (Farrell et al. 1979; Davis et al. 1979) has been used as a submaximal indicator of conditioning. However it has been demonstrated that intensities of 85% $\dot{V}O_2$ max (Kindermann et al. 1979) and 86% $\dot{V}O_2$ max (Costill et al. 1971) which are markedly higher than the anaerobic threshold, can be maintained for prolonged periods of time. However, differences in terminology, and the suggestion of an aerobic-anaerobic transition phase (Kindermann et al. 1979; Skinner and McLellan, 1980) have complicated the functional significance and training application of these measurements.

Attention during the last decade to the contractile and metabolic properties of different types of muscle fibres, has focussed on the characteristics of skeletal muscle of endurance athletes. In this regard, significant relationships between $\dot{V}O_2$ max and type I fibre percentage has been reported (Ivy et al. 1980; Rusko et al. 1978). These athletes have been found to have high percentages of the predominately aerobic type I fibres whereas power event athletes have a greater proportion of the highly glycolytic type II fibres (Forsberg et al. 1976). The published data clearly demonstrate that although the average muscle fibre composition for a group of endurance athletes is skewed towards type I fibres, many successful individuals have similar percentages of type I and type II fibres (Gollnick et al. 1980). Furthermore, elite power event athletes do not necessarily have high percentages of type II fibres (Saltin et al. 1977). Although interacting relationships seem

to exist between some of the cellular characteristics and performance, the characteristics have not been established as good performance predictors (Gollnick et al. 1980).

An analysis of predictive laboratory and field tests used to evaluate endurance reveal differences in the primary energy source taxed during the tests and wide variations in the intensity and duration of effort (Burke, 1976). In the laboratory situation, a wide variety of dependent variables have been used. Some investigators (Houston et al. 1979) assess performance time, while others (Costill et al. 1973; Farrell et al. 1979) measure $\dot{V}O_2$ max and heart rate responses at a fixed treadmill speed. In field test situations, distance runs over 2000 or 3000 metres (Waibaum and Tschekulyor, 1977) as well as distance covered in 12 minutes (Cooper, 1968) are used to evaluate aerobic capacity. However, subject motivation and pace judgment have been suggested to diminish the accuracy of the latter tests (Cooper, 1968).

Endurance capability is normally associated with long distance running events or activities that require a continuous effort for more than 30-40 minutes. However, endurance can also be considered a component of shorter duration activities of high intensity. The intermittent nature of play, and duration of a game in such activities as basketball, volleyball and ice-hockey, requires a developed aerobic capacity in order to facilitate rapid recovery during periods of rest. This aspect of conditioning has tended to be neglected during the competitive season at the expense of high intensity, skill oriented practice or game situations. Furthermore, there has been limited research into assessing the nature of endurance in intermittent high-intensity activities.

Although many studies have demonstrated predictive relationships between laboratory, field and performance measures of endurance, these

relationships are not sufficiently robust when used within homogeneous populations. Since at least two different types of endurance performance have been described, it is important that laboratory and field measures be established which accurately reflect these different endurance components. Thus the purpose of this study is to determine which selected laboratory and field measures best reflect the different types of endurance performance so that accurate assessment of the training state can be carried out and precise training programmes formulated.

The Problems are:

1. To determine which predictive and functional characteristics relate to the different types of endurance performance.
2. To determine the selected laboratory and field tests which best reflect the different types of endurance.
3. To determine whether differences in endurance characteristics exist between homogeneous activity groups.
4. To develop a physiological rationale for classifying different types of endurance.

OPERATIONAL DEFINITIONS

Maximal oxygen uptake: refers to the maximal volume of oxygen which can be consumed per minute ($l \cdot min^{-1}$ or $ml \cdot kg^{-1} \cdot min^{-1}$) during a progressive exercise.

Anaerobic threshold (Wasserman): is characterized by a non-linear increase in $\dot{V}_E$ and $\dot{V}CO_2$ plus a rise in blood lactate from approximately 2 $mmol \cdot l^{-1}$.

Aerobic threshold (AeT) (formerly anaerobic threshold): is characterized by the first non-linear increase in $\dot{V}_E$ and the ventilatory equivalent ($\dot{V}_E/\dot{V}O_2$).

Anaerobic threshold (AnT): is characterized by the second non-linear increase in $\dot{V}_E$ and the ventilatory equivalent ($\dot{V}_E/\dot{V}O_2$).

Factor analysis: is a method of exploration in regions unstructured by present knowledge yielding evidence as to the strength of association between variables.

METHODOLOGY

Subjects

The subjects were 70 volunteer male university students of the University of Alberta. The subject pool, 10 subjects per group, consisted of five competitive (intercollegiate) groups; basketball, wrestling and judo, ice-hockey, volleyball, and endurance (cross-country running and skiing), and two non-competitive groups of recreational athletes. Their age, height and weight were (mean $\pm$ SEM) 21.3 $\pm$ 0.4 yr, 178.4 $\pm$ 22.8 cm, 75.8 $\pm$ 1.1 kg, respectively.

Testing Procedures and Orientation

All subjects were tested in 30 minute sessions on four different days. In any one week, 10 subjects were given all four tests in a fixed order. In the week prior to testing, each group reported for orientation, and were familiarized with the equipment and testing procedures. The competitive groups were tested just prior to their competitive season.

Submaximal Treadmill Run

This test was a 10 minute, submaximal treadmill run (Costill et al. 1973) at a speed of 215 $m \cdot min^{-1}$ ($7\frac{1}{2}$ $min \cdot mile^{-1}$). The test was preceded by a six minute warm-up on a bicycle ergometer at an intensity that elicited a heart rate of between 130-150 $b \cdot min^{-1}$. $\dot{V}O_2$ and heart rate were monitored during the last three minutes of the test. Within 30 s after the test, a blood sample was taken from the ante-cubital vein for lactate determination from volunteer subjects.

Aerobic and Anaerobic Threshold and $\dot{V}O_2$ max

The thresholds and $\dot{V}O_2$ max were determined during a continuous run on a treadmill. The speed was increased by $\sim$0.8 $km \cdot h^{-1}$ every 1½ minutes. The gradient was increased by 2% every minute during the final stages of the test until exhaustion or the levelling off of $\dot{V}O_2$ (Taylor et al. 1955). The aerobic and anaerobic thresholds (Kindermann et al. 1979) were determined by abrupt change in $\dot{V}_E$ and O_2 equivalent ($\dot{V}_E/\dot{V}O_2$) by one investigator and reported in absolute ($\dot{V}O_2$ $ml \cdot kg^{-1} \cdot min^{-1}$ and speed $km \cdot h^{-1}$) and relative (% $\dot{V}O_2$ max) terms (Figure 1).

Endurance Run

Each group was timed over a 5000 m run on a 400 m tartan track. The subjects ran together in a competitive situation and were encouraged to run the distance as fast as possible. Lap times were given to aid pace judgment.

Repeated High Intensity Endurance Test (RHIET)

The test involved a 40 m sprint followed by a stop (touching a 35 x 42 cm target suspended at waist height) and return in the opposite direction to the start line. The subjects performed 6 "all-out" timed repeats, at 30 s intervals, each work interval beginning at time 0, ½, 1, 1½, 2 and 2½ minutes. The exercise internal ranged from 12-15 s and the recovery interval from 18-15 s. Heart rates were recorded immediately following the sixth repeat and at 1, 2 and 3 minutes post exercise. A blood sample was taken at 3 minutes post exercise from the volunteer subjects (n = 33).

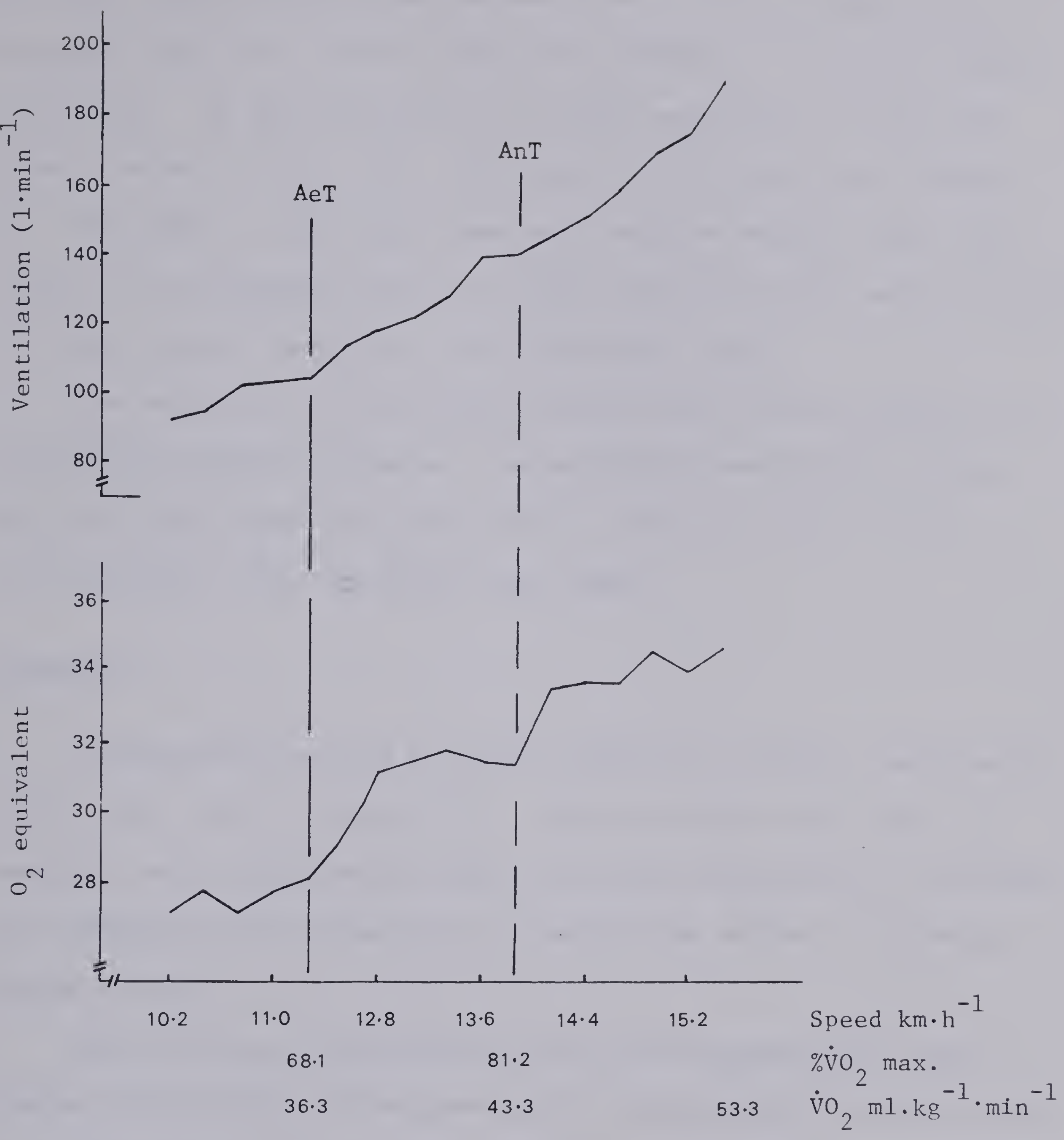

Figure 1: Method of determining relative and absolute aerobic and anaerobic threshold for one subject.
($\dot{V}_E$, expired air, l·min^{-1}; O_2 equivalent, $\dot{V}_E/\dot{V}O_2$)

The repeats were timed by hand and with a photo-electric system. The time taken to sprint from the start line to the turn and back to the start line (total distance 80 m) was measured on a hand-held digital stop watch. The photo-electric cell timers were placed 5 m from the start line and the turn line. The sum of (2) 30 m times was recorded for each repeat. Each repeat time and a relative drop-off index calculated as the difference between the first and sixth repeat were calculated. All times reported are those of photo-electric timing.

The reliability of the testing procedure was studied separately on 12 physical education students. The reliability coefficients between the test-retest (one week between tests) values were 0.91, 0.79 and 0.72 for first, third and sixth repeat times.

Apparatus

A Beckman MMC was used to measure expired gas volume, concentration of CO_2 and O_2 and to calculate $\dot{V}O_2$. Before and after each test, the analysers were calibrated with gases of known concentration. The volume was calibrated each morning prior to testing and checked at intervals during the day.

Heart rates were monitored both electrocardiographically using a Sandborn Visicardette 500 recorder and by cardiotacometer (Cardionic ab Stockholm) during all laboratory trials. An Exersentry (Respironics Inc.) was used for the repeated high intensity endurance test, and times were recorded using photo-electric timing equipment (Lafayette Instrument Co., Indiana). The blood lactates were determined by an enzymatic method (Sigma).

Statistical Methods

The data were analyzed with either a one-way analysis of variance (Winer, 1971) or with factor analysis (Cattel, 1973). The principal factor solution (Harman, 1960) was rotated using varimax orthogonal solution (Kaiser, 1958) and oblique solution (Harris and Kaiser, 1964).

Post-hoc procedures involved Scheffé's contrast method (Scheffé, 1953) for locating significant mean differences. Significant differences were accepted at the alpha level p is less than 0.01 where p is the probability that no difference exists between means. Correlations between selected variables were computed using the Pearson product moment procedure (Winer, 1971).

RESULTS

The physical, physiological and performance results are summarized ($\bar{X} \pm$ SEM) in Table 1. In comparison to all other groups the endurance group had better 5000 m speed, speed at AnT and $\dot{V}O_2$ max (except hockey) and had lower heart rates at 215 $m \cdot min^{-1}$ (except basketball) (Table 1). The endurance group also exceeded the two mixed groups on $\dot{V}O_2$ at 180 $b \cdot min^{-1}$ and speed at AeT. There was no difference (Appendix E-18 and E-19) between any group in submaximal lactate concentration after the treadmill run at 215 $m \cdot min^{-1}$ and in maximal lactate concentration after the repeated high intensity endurance test (RHIET) (Table 2). No differences were found between groups on the first, third, sixth or the relative drop-off times. The correlations between 5000 m speed and the relative drop-off index and sixth repeat time are presented in Table 4. Significant differences (Scheffé comparison test) between activity groups on different physical, physiological and performance measures are summarized in Table 3. Percent maximal heart rate at 215 $m \cdot min^{-1}$ and speed at AnT correlated with 5000 m speed 0.81 and 0.87 respectively; the standard error of estimates being 14.6 $m \cdot min^{-1}$ and 12.2 $m \cdot min^{-1}$ respectively. The correlation between 11 selected physiological variables for all groups, used for factor analysis is summarized in Appendix B-1.

TABLE 1: Physical, physiological and performance data for the different activity groups (X ± SEM)

	Age (yrs)	Height (cms)	Weight (kg)	HR at 215 $m \cdot min^{-1}$ ($b \cdot min^{-1}$)	$\dot{V}O_2$ at 215 $m \cdot min^{-1}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ at 180 $b \cdot min$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Speed at AeT ($km \cdot hr^{-1}$)	% $\dot{V}O_2$ max at AeT (%)	Speed at AnT ($km \cdot hr^{-1}$)	% $\dot{V}O_2$ max at AnT (%)	Relative Drop-Off (s.)	Recovery HR at 2 min ($b \cdot min^{-1}$)	First Repeat Time (FRT) (s.)	Third Repeat Time (TRT) (s.)	Sixth Repeat Time (SRT) (s.)	5000 m speed ($km \cdot hr^{-1}$)
Basketball	19.2	192.4	81.0	167.2	45.3	56.9	55.9	13.2	77.3	15.2	89.9	2.02	119.2	8.70	9.99	10.72	14.4
	0.5	2.2	2.9	1.8	0.8	1.1	1.7	0.4	2.0	0.2	0.8	0.21	4.0	0.13	0.20	0.27	0.2
Wrestling	19.9	171.4	72.9	170.1	42.9	61.8	52.3	12.6	65.3	15.4	86.5	1.75	120.0	8.41	9.82	10.16	14.9
	0.9	2.0	3.5	5.4	0.7	0.8	2.6	0.5	2.1	0.3	3.2	0.13	2.9	0.10	0.13	0.10	0.4
Ice-Hockey	19.8	180.7	77.5	175.7	46.0	62.1	52.8	13.2	72.5	15.0	82.7	1.96	130.0	8.20	9.42	10.16	15.0
	0.5	2.1	3.3	3.2	1.1	1.2	1.3	0.4	1.6	0.2	0.8	0.15	3.2	0.10	0.13	0.11	0.2
Endurance	23.0	180.4	68.9	146.7	42.7	68.1	62.6	14.8	71.5	17.1	88.1	1.55	119.8	8.60	9.43	10.15	17.8
	0.5	1.2	2.0	2.7	0.9	1.9	1.8	0.4	2.6	0.2	2.2	0.18	4.7	0.08	0.12	0.16	0.4
Volleyball	19.7	186.2	78.6	172.4	43.5	58.4	52.6	12.6	68.4	15.1	85.5	2.09	132.6	8.10	9.38	10.19	14.1
	0.3	1.9	1.5	2.5	0.8	0.7	1.4	0.3	1.9	0.1	2.1	0.13	2.7	0.10	0.08	0.09	0.1
Mixed I	25.4	178.4	78.0	171.6	44.0	53.9	46.9	11.9	72.1	15.0	91.4	2.19	120.3	8.50	10.06	10.69	14.7
	1.0	3.6	3.0	2.6	0.8	1.5	2.0	0.5	2.7	0.3	1.6	0.21	3.2	0.09	0.14	0.21	0.2
Mixed II	22.1	177.4	73.5	172.6	43.6	56.3	50.1	11.9	69.7	14.9	88.1	1.63	128.5	8.52	9.83	10.15	14.5
	1.0	2.9	2.2	4.4	0.8	1.1	1.5	0.5	2.7	0.3	1.5	0.29	6.4	0.15	0.10	0.15	0.4
X ± SEM	21.3	181.0	75.8	168.0	44.0	59.6	53.3	12.9	71.0	15.4	87.4	1.88	124.3	8.43	9.70	10.32	15.0
	0.4	1.1	1.1	1.6	0.3	0.7	0.8	0.2	0.9	0.1	0.8	0.07	1.6	0.05	0.06	0.07	0.2

TABLE 2: Submaximal and maximal lactate concentrations for volunteers within the different activity groups (n = 33)

Group	n	Submaximal [a] lactate concentration mg %	Maximal [b] lactate concentration mg %
Basketball	4	31.4 ± 2.1	119.4 ± 3.6
Wrestling	5	32.4 ± 2.6	150.2 ± 7.2
Ice-Hockey	5	32.6 ± 0.8	142.3 ± 2.5
Endurance	4	19.0 ± 1.1	151.2 ± 5.3
Volleyball	5	41.1 ± 1.7	141.5 ± 3.1
Mixed I	5	41.8 ± 2.5	120.7 ± 2.3
Mixed II	5	25.7 ± 2.0	125.1 ± 4.1
$\bar{X}$	33	32.4 ± 2.1	135.8 ± 4.3

Values are $\bar{X} \pm$ SEM

[a] concentration after 10 min run at 215 $m \cdot min^{-1}$ (immediate post exercise)

[b] concentration after repeated high intensity endurance test (3 min post exercise)

TABLE 3: Significant differences between activity groups ($p < 0.01$) on the different physical, physiological and performance measures

GROUP COMPARISON		Age (yrs)	Height (cms)	Weight (kg)	HR at 215 $m \cdot min^{-1}$ ($b \cdot min^{-1}$)	$\dot{V}O_2$ at 215 $m \cdot min^{-1}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ max ($ml \cdot kg \cdot min^{-1}$)	$\dot{V}O_2$ at 180 $b \cdot min^{-1}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Speed at AeT ($km \cdot h^{-1}$)	% $\dot{V}O_2$ max at AeT (%)	Speed at AnT ($km \cdot h^{-1}$)	% $\dot{V}O_2$ max at AnT (%)	Relative Drop-Off (s)	Recovery HR at 2 min ($b \cdot min^{-1}$)	First Repeat Time (s)	Third Repeat Time (s)	Sixth Repeat Time (s)	5000 m speed ($km \cdot h^{-1}$)
Endurance	vs Hockey				x						x							x
	vs Basketball						x				x							x
	vs Wrestling				x		x				x							x
	vs Volleyball				x		x				x							x
	vs Mixed I				x		x	x	x		x							x
	vs Mixed II		x		x		x	x	x		x							x
Basketball	vs Wrestling		x															
	vs Mixed I	x																
Wrestling	vs Mixed I	x					x											
Hockey	vs Mixed I	x					x											
Volleyball	vs Mixed I	x																
ANOVA F value Critical F 6,63 at 0.01 = 3.10 at 0.05 = 2.24		7.53	7.48	2.31	8.10	2.06	14.10	7.39	5.69	2.71	8.58	2.30	1.58	2.02	3.99	4.43	2.49	14.71

x denotes superior score

TABLE 4: Correlations between 5000 m speed and the relative drop-off index and sixth repeat time

Correlation between 5000 m speed	Relative Drop-Off	Sixth Repeat Time
Basketball	-0.76	-0.79
Wrestling	-0.72	-0.55
Ice-Hockey	-0.17	-0.24
Endurance	-0.51	-0.52
Volleyball	-0.18	-0.33
Mixed I	-0.69	-0.74
Mixed II	-0.42	-0.62
n = 70	-0.44	-0.37

FACTOR ANALYSIS

In order to determine which performance and physiological variables loaded together, three sets of data were analyzed with factor analysis. All groups were included in the first analysis (A) of 11 dependent variables. In the second analysis (B) only competitive groups were included (n = 50). The third analysis (C) was of 13 variables which included submaximal and maximal lactate concentrations (n = 33).

In all three analyses, the first three eigen values of the principal components analysis were larger than unity, and these factors were retained for rotation (Kaiser, 1960). The orthogonal and oblique solutions are presented in Tables 5 (analysis A), 6 (analysis B), and 7 (analysis C). Factor correlations for the oblique solutions are summarized in Table 8.

Both orthogonal and oblique solutions yielded similar results and those variables with consistant factor loadings greater than 0.60 in all three analyses are presented in Table 9.

In the three analyses, 5000 m speed was identified as a marker variable for Factor I, sixth repeat time as a marker for Factor 2, and third repeat time as a marker for Factor 3.

TABLE 5: Analysis A, Orthogonal and oblique rotated factor matrices and communalities for all the activity groups (n = 70)

	Orthogonal Solution				Oblique Solution			
	F_1	F_2	F_3	h^2	F_1	F_2	F_3	h^2
$\dot{V}O_2$ max	0.69	0.36	0.39	0.73	0.64	0.27	0.26	0.55
$\dot{V}O_2$ at 180 $b \cdot min^{-1}$	0.80	0.07	-0.09	0.65	0.81	0.01	-0.25	0.72
Speed at AeT	0.89	-0.13	-0.11	0.83	0.97	-0.21	-0.34	1.10
Speed at AnT	0.88	0.23	-0.09	0.83	0.85	0.17	-0.24	0.81
5000 m speed	0.82	0.27	0.01	0.75	0.79	0.21	-0.12	0.68
% $\dot{V}O_2$ max at AeT	0.39	-0.66	-0.38	0.74	0.57	-0.69	-0.60	1.16
Relative Drop-Off	-0.33	-0.82	0.17	0.82	-0.12	-0.86	0.08	0.76
6th Repeat time	-0.30	-0.81	-0.21	0.79	-0.10	-0.79	-0.31	0.73
% $\dot{V}O_2$ max at AnT	0.13	-0.24	-0.62	0.46	0.17	-0.19	-0.69	0.54
Recovery HR at 2 min	0.28	-0.32	0.74	0.73	-0.17	-0.41	0.72	0.71
3rd Repeat time	0.33	-0.16	-0.74	0.69	-0.34	-0.04	-0.68	0.58
% of total variance	35.6	20.3	16.9	72.8	33.9	20.4	21.5	75.8
Cumulative % of variance	35.6	55.9	72.8	-	33.9	54.3	75.8	-

TABLE 6: Analysis B, Orthogonal and oblique rotated factor matrices and communalities for the competitive activity groups (n = 50)

	Orthogonal Solution				Oblique Solution			
	F_1	F_2	F_3	h^2	F_1	F_2	F_3	h^2
VO_2 max	$\boxed{0.64}$	0.42	-0.22	0.64	0.59	0.36	-0.22	0.53
VO_2 at 180 $b \cdot min^{-1}$	$\boxed{0.78}$	-0.08	0.25	0.67	$\boxed{0.80}$	-0.13	0.46	0.87
Speed at AeT	$\boxed{0.87}$	-0.23	0.02	0.81	$\boxed{0.95}$	-0.32	0.34	1.12
Speed at AnT	$\boxed{0.90}$	0.16	0.09	0.84	$\boxed{0.88}$	0.10	0.24	0.86
5000 m speed	$\boxed{0.86}$	0.25	-0.04	0.81	$\boxed{0.84}$	0.18	0.07	0.73
% VO_2 max at AeT	0.32	$\boxed{-0.81}$	0.13	0.78	0.51	$\boxed{-0.88}$	0.56	1.35
Relative Drop-Off	-0.44	$\boxed{-0.72}$	-0.27	0.79	-0.26	$\boxed{-0.77}$	-0.05	0.66
6th Repeat time	-0.28	$\boxed{-0.79}$	0.20	0.75	-0.12	$\boxed{-0.80}$	-0.46	0.87
% VO_2 max at AnT	0.14	-0.39	0.45	0.38	0.19	-0.37	$\boxed{0.63}$	0.57
Recovery HR at 2 min	-0.28	-0.19	$\boxed{-0.83}$	0.81	-0.16	-0.29	$\boxed{-0.77}$	0.70
3rd Repeat time	-0.29	-0.29	$\boxed{0.75}$	0.74	-0.31	-0.18	$\boxed{0.76}$	0.71
% total variance	35.4	21.9	15.6	72.9	33.5	20.4	17.6	81.5
Cumulative % of variance	35.4	57.3	72.9	-	33.5	53.9	81.5	-

TABLE 7: Analysis C, Orthogonal and oblique rotated factor matrices and communalities for a random sample of the competitive and non-competitive groups (n = 33)

	Orthogonal Solution				Oblique Solution			
	F_1	F_2	F_3	h^2	F_1	F_2	F_3	h^2
$\dot{V}O_2$ max	0.51	0.42	-0.57	0.76	0.46	0.48	-0.59	0.79
$\dot{V}O_2$ at 180 $b \cdot min^{-1}$	0.82	0.06	-0.08	0.68	0.80	0.17	-0.12	0.68
Speed at AeT	0.87	-0.18	-0.03	0.79	0.89	-0.06	-0.08	0.80
Speed at AnT	0.89	0.23	-0.04	0.85	0.84	0.35	-0.09	0.84
Submax [lactate]	-0.77	-0.31	-0.21	0.74	-0.69	-0.41	-0.17	0.67
5000 m speed	0.79	0.35	-0.02	0.75	0.71	0.46	-0.06	0.72
% $\dot{V}O_2$ at AeT	0.52	-0.62	0.34	0.76	0.61	-0.54	0.29	0.75
Relative Drop-Off	-0.25	-0.82	-0.21	0.79	-0.07	-0.86	-0.22	0.79
6th Repeat time	-0.20	-0.91	0.13	0.88	-0.02	-0.93	0.11	0.88
% $\dot{V}O_2$ at AnT	0.50	-0.20	0.71	0.80	0.49	-0.12	0.68	0.72
Recovery HR at 2 min	-0.18	-0.25	-0.65	0.52	-0.10	-0.28	-0.65	0.51
Max [lactate]	0.10	0.09	-0.79	0.65	0.16	0.08	-0.80	0.67
3rd Repeat time	-0.23	-0.31	0.78	0.75	-0.21	-0.33	0.79	0.78
% of total variance	34.0	19.8	20.9	74.7	31.3	21.7	20.8	73.8
Cumulative % of variance	34.0	53.8	74.7	-	31.3	53.0	73.8	-

TABLE 8: Summary of factor correlations for oblique solutions of factor analysis A, B and C

Correlation between	FACTOR ANALYSIS A	B	C
Factor 1 v 2	0.33	0.26	-0.24
1 v 3	0.20	-0.15	0.11
2 v 3	-0.03	0.26	-0.05

(A) - This factor includes 7 groups and 11 variables

(B) - This factor includes 5 groups and 11 variables

(C) - This factor includes a random sample of each of the 7 groups and 13 variables which include the submaximal and maximal lactate concentrations

TABLE 9: Summary of factor analysis findings of analysis A, B and C. Variables selected with consistent factor loadings > 0.60.

FACTOR 1	FACTOR 2	FACTOR 3
Speed at AnT	% $\dot{V}O_2$ max at AeT	Max [lactate]
Speed at AeT	Sixth repeat time	Recovery HR at 2 min
$\dot{V}O_2$ at 180 $b \cdot min^{-1}$	Relative drop-off	% $\dot{V}O_2$ max at AnT
Submaximal [lactate]		Third repeat time
$\dot{V}O_2$ max		
5000 m speed		

DISCUSSION

The factor analysis findings of this study suggest that a continuum of endurance, from short duration high intensity to prolonged duration, may be divided into three distinct factors with the overlap or correlation between factors being dependent upon the sample tested (Table 7). It is probable that training may influence the degree of correlation between the factors. Previous field evaluations of physical fitness using running tests have suggested two distinct factors exist, running endurance and running speed (Linden, 1977; Disch et al. 1975; Fleischman, 1964). Running tests greater than 600 yds have been used to evaluate aerobic power while shorter distances have been used to reflect anaerobic power. Linden (1977) factor analyzed data from eight Olympic decathlons and found that the 100 m and 400 m loaded highly on one factor which was interpreted as running speed. The 1500 m run represented another factor designated as endurance. However, one of the major limitations of factor analysis is that the factors isolated are dependent upon the number and type of variables included in the correlation matrix (Disch, 1979). A dimension will not be defined if no test or variable is selected to represent it. Although Linden (1977) interpreted the 1500 m run as representing endurance, the present study indicates that this distance may be between the two extremes of running speed and endurance.

The methodology of factor analysis has been utilized to examine domains of flexibility (Harris, 1969), body composition (Jackson and Pollock, 1976), and distance runs (Disch et al. 1975). Few studies have attempted to select variables that may shed light upon the underlying mechanisms of a selected factor. The general approach (Jackson and Frankiewicz, 1975; Disch et al. 1975; Fleischman, 1964) has been

to select various tests and through the technique of factor analysis describe specific constructs in relation to a hypothesized domain and thus validate the use of those tests as quantitative measures of specific aspects of that domain. In this study, the technique of factor analysis has been used in both a confirmatory and exploratory way; to confirm the use of established tests of endurance, and to examine underlying physiological components of the domain of endurance. Therefore, a physiological rationale for the variables which load highly on the different factors will now be developed.

Factor III

The energy demand of short duration maximal intensity exercise requires a predominant anaerobic metabolism, this predominance lasting up to about 2 min (Astrand and Rodahl, 1977). The third repeat time had a high loading on this factor and was selected as a performance indicator of anaerobic endurance. Maximal lactate concentration, % $\dot{V}O_2$ max at AnT and recovery heart rate at 2 minutes also had high loadings (Table 7). It should be noted that recovery heart rate of 2 minutes is associated with these variables and not those normally related to aerobic capacity.

Tesch (1978, 1980) demonstrated a relationship between lactate concentration and performance time ($r = 0.76$) and noted that those subjects rich in type II fibres had longer performance times. Performance time ranged from 99 s to 126 s. The results also demonstrated that within the same muscle, type II fibres produced more lactate compared to type I fibres.

Although a different performance criterion was used by Tesch, the inverse factor loadings of maximal lactate concentration (0.80) to third

repeat time (-0.79) (Table 6) would suggest that a high anaerobic ability may play an important role in speed generation. A significant correlation ($r = -0.46$; $p < 0.01$) was demonstrated between the two variables.

The relative values of anaerobic threshold (AnT) determined in this study are very similar to those reported by Kindermann et al. (1979) (Appendix C). Those athletes engaged in sports demanding high anaerobic power tend to have lower relative AnT scores than endurance athletes, although there is a wide intra-group variation.

Factor II

The sixth repeat time of the repeated high-intensity endurance test (RHIET) was selected to represent the ability to maintain near maximal speed under anaerobic conditions. This variable (SRT) together with the relative drop-off time, calculated as the difference in time between the first and sixth repeats, and % $\dot{V}O_2$ at AeT had high loadings on this factor. During intense exercise the recruitment of both type I and type II fibres has been demonstrated (Essen, 1978; Gollnick et al. 1974) and Skinner and McLellan (1980) have suggested that the increasing recruitment of type II fibres may be associated with the aerobic threshold and as well the % $\dot{V}O_2$ max at AeT. During the RHIET, type II fibre involvement may be very substantial since rapid tension would be required to start each repeat, to slow down for the turn, and to accelerate again on the return portion of the repeat.

Muscle fibre composition, particularly the proportion of type IIA and type IIB, and the effects of training on their distribution, may have a significant influence on % $\dot{V}O_2$ max at AeT. Increased proportion of IIA:IIB fibres have been reported (Jansson and Kaiser, 1977; Andersen and Henriksson, 1977) and regularly performed endurance exercise results

in this adaptive conversion (for review, see Houston, 1978). Biochemical studies of type II fibres have revealed a high oxidative potential (SDH activity) and low glycolytic potential (PFK activity) in IIA fibres and opposite potentials in IIB fibres (Jansson, 1975). This enhanced oxidative potential may then be reflected in an elevated % $\dot{V}O_2$ max at AeT.

The fraction of $\dot{V}O_2$ max at which the aerobic threshold occurs has been shown to change with training (Davis et al. 1979) and athletes have higher AeT values than non-athletes (MacDougall, 1977) (Appendix D). The mode of eliciting $\dot{V}O_2$ max may have an influence on relative AeT values, since higher $\dot{V}O_2$ max values are obtained during treadmill running compared to bicycle ergometry (Glassford et al. 1965).

Previous investigators (Davis et al. 1979; Weltman et al. 1978; Davis et al. 1976) have correlated $\dot{V}O_2$ at AeT and $\dot{V}O_2$ max and reported values from $r = 0.52$ to 0.85. The prediction of $\dot{V}O_2$ max from % $\dot{V}O_2$ max at AeT (Weltman et al. 1979) has also been suggested. The range of these correlations suggest that the measurements are for the most part, measurements of different physiological phenomena (Davis et al. 1979). The results of the factor analyses confirm this; $\dot{V}O_2$ max loading on factor I and % $\dot{V}O_2$ max at AeT loading on factor II. Factor II, however, may show some correlation with factor I. This is indicated by the data presented in Table 4 which demonstrates that the degree of correlation between 5000 m speed (the performance marker of factor I) and sixth repeat time (the performance marker of factor II) differ according to the activity group. This would suggest that some relationship exists between the two factors and may be sport specific. Both ice-hockey and volleyball, two sports demanding repeated high intensity work with short recovery intervals, have low correlations between the 5000 m speed and both the relative drop-off index and sixth repeat time, whereas basketball,

wrestling and endurance show high correlations. These latter sports demand more continuous effort at a high intensity.

Factor I

High factor loadings on factor I were demonstrated by the 5000 m speed, which was selected as a criterion measure of endurance and both $\dot{V}O_2$ max and the submaximal lactate concentration. The latter two have previously been shown to be physiological variables important to endurance performance. Other variables with high loadings were speed at aerobic threshold, speed at anaerobic threshold and $\dot{V}O_2$ at 180 $b \cdot min^{-1}$ (Table 9). The latter, $\dot{V}O_2$ at 180 $b \cdot min^{-1}$, was selected to represent cardiovascular efficiency and had a higher loading than $\dot{V}O_2$ max on factor I.

Previous research (Balke, 1952) proposed that a submaximal heart rate (180 $b \cdot min^{-1}$) be used to measure circulorespiratory capacity and endurance. Other researchers have consistantly demonstrated an increase in stroke volume at any level of exercise as well as rest (Clausen, 1977) and a slower heart rate (Scheuer and Tipton, 1977; Lewis et al. 1980) as a result of endurance training. The accompanying increases in cardiac output (Ekblom and Hermansen, 1968; Saltin et al. 1968; Ekblom et al. 1968) and $\dot{V}O_2$ at specific workloads may require improvement in both central (cardiac volume, mycardial contractility, total blood volume) and peripheral (total peripheral resistance, regional blood flow, degree of capillarization, muscle oxidative potential) factors (Clausen, 1977; Saltin and Rowell, 1980). These variables may all contribute, in varying degrees, to increased circulorespiratory capacity, indicated by observed increases in stroke volume and arterio-venous difference.

Circulorespiratory capacity, represented by a reduction in exercise heart rate at a given submaximal workload (Scheuer and Tipton, 1977; Winder et al. 1978) may also be influenced by a reduction in sympathetic drive to the heart and/or increased parasympathetic drive. The mechanism for the training-induced decline in catecholamine response to exercise is not presently known, but may be partially dependent on intramuscular adaptations (Winder et al. 1978). In one-legged experiments, lowered submaximal exercise heart rates are restricted to exercise with the trained leg only (Saltin, 1977). This may be because chemical stimuli such as elevated potassium and osmolarity also effect cardiovascular responses (Mitchell et al. 1977; Wildenthal et al. 1968; Tibes et al. 1973).

Functional endurance capacity has previously been reflected by $\dot{V}O_2$ max (Saltin and Rowell, 1980) since high values have correlated with successful endurance performance (Costill, 1967; Costill et al. 1973; Foster et al. 1978; Farrell et al. 1979). Since $\dot{V}O_2$ at 180 $b \cdot min^{-1}$ loads higher on factor I (Tables 5, 6 and 7), it may be a better measure of functional endurance capacity and circulorespiratory capacity particularly in a homogeneous group of endurance athletes, all of whom have high $\dot{V}O_2$ max values. $\dot{V}O_2$ max is important to endurance capacity, but the central and peripheral changes brought about by endurance training may be reflected to a greater extent in $\dot{V}O_2$ at 180 $b \cdot min^{-1}$.

Both speed at AeT and AnT loaded highly on factor I. The onset of plasma lactate accumulation velocity (OPLAVEL) (a variable similar to speed at AeT in this study) has previously been demonstrated to be highly correlated with endurance performance ($r \geq 0.91$, Farrell et al. 1979). However, speed at AnT, which has not been previously investigated, correlated highest (Appendix B-1) with 5000 m speed ($r = 0.87$; standard error of estimate 12.2 $m \cdot min^{-1}$; $p < 0.001$), and may be a good laboratory

indicator of "endurance performance". The predictive equation from the present data is

$$5000 \text{ m speed } (\text{m}\cdot\text{min}^{-1}) = -3.63 + 1.212 \text{ speed at AnT } (\text{m}\cdot\text{min}^{-1})$$

Although both speed at AeT and AnT are indicators of 5000 m performance, speed at AeT may be a better index of 20 km and 42.2 km performance ability since the relative intensities of the laboratory measure ($\simeq$ 70% $\dot{V}O_2$ max) and performance ($\simeq$ 75% $\dot{V}O_2$ max, Farrell et al. 1979) are similar. On the other hand, speed at AnT may be indicative of 5 km and 10 km performance ability because of the similarity of relative intensity (85% $\dot{V}O_2$ for 10 km); Farrell et al. 1979 versus 85% $\dot{V}O_2$ max for speed at AnT).

The other variable which correlated with 5000 m speed was % maximal heart rate at 215 $\text{m}\cdot\text{min}^{-1}$ ($r = 0.81$; standard error of estimate 14.7 $\text{m}\cdot\text{min}^{-1}$; $p < 0.001$). This variable may also be a predictor when maximal heart rate can be determined. The predictive equation from the present data is

$$5000 \text{ m speed } (\text{m}\cdot\text{min}^{-1}) = 546.3 - 3.34 \cdot \% \text{ max HR at } 215 \text{ m}\cdot\text{min}^{-1}$$

Other researchers have reported a similar relationship ($r = 0.86$; standard error of estimate 19.0 $\text{m}\cdot\text{min}^{-1}$) for the prediction of 3.2 km speed from % maximal heart rate at 268 $\text{m}\cdot\text{min}^{-1}$ (Farrell et al. 1980).

PHYSIOLOGICAL MODEL FOR THE CONTINUUM OF ENDURANCE

The technique of factor analysis revealed three distinct factors representing a continuum from high speed endurance to prolonged low intensity efforts, as indicated by the marker variables (third repeat time-speed; sixth repeat time-speed endurance; 5000 m speed-endurance). The presented factors may be interpreted in physiological terms as anaerobic endurance (factor III), anaerobic-aerobic endurance (factor II) and aerobic endurance (factor I). A physiological model representing the contribution of these factors to a proposed continuum of endurance will now be developed.

Anaerobic Endurance Factor III

It has previously been established that the energy required for the first 8-15 s of intense exercise is derived from the initial energy stores of ATP and CP (Margaria et al. 1964; Hultman et al. 1967; Saltin and Essen, 1971) with no or little accumulation of plasma lactate. This is considered as the first system contributing to the endurance continuum.

After about 10 s work, energy derived from anaerobic glycolytic metabolism contributes significantly to the total energy requirement, reaching a maximal rate at approximately 40 s, as indicated by lactate accumulation (Margaria et al. 1964). Karlsson (1971) demonstrated that repeated maximal or near maximal bursts of activity of 1 min duration led to maximal muscle lactate concentrations as early as at the end of the first exercise bout. Thus, maximal performances from 10 s to approximately 90 s, encompass the time when maximal lactate concentration may be reached. The first three repeats in the RHIET (figure 2) are suggested to represent this "anaerobic endurance phase" and

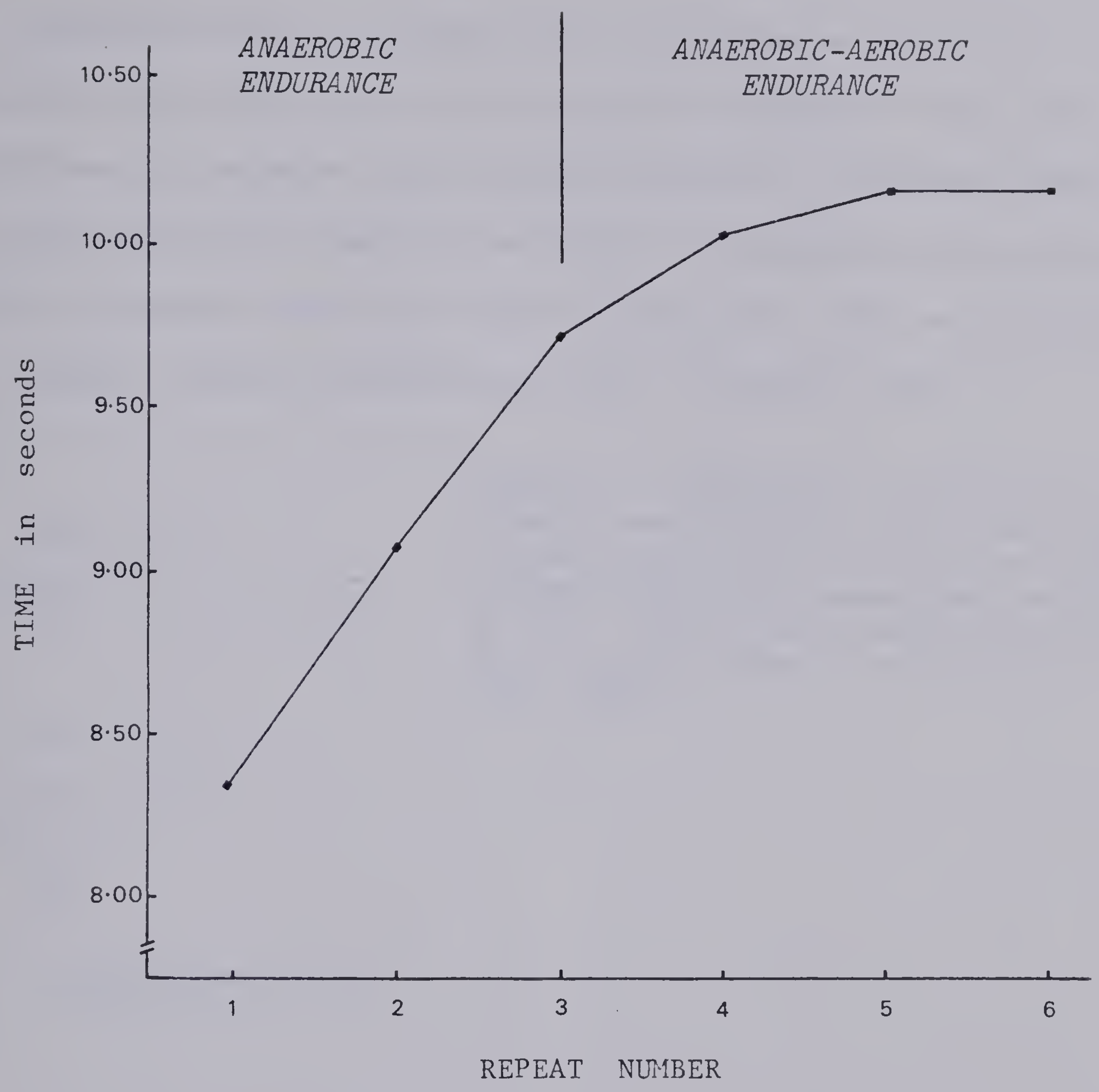

Figure 2: Mean time for all activity groups, for each repeat, during the repeated high-intensity endurance test (RHIET). Repeats 1-3 represent anaerobic endurance and repeats 4-6 represent anaerobic-aerobic endurance.

correspond to factor III in the factor analysis.

Anaerobic-Aerobic Endurance - Factor II

Anaerobic-aerobic endurance may be described as the ability to maintain near maximal speed under anaerobic conditions during both continuous and repeated high intensity exercise. The time at which the task shifts from anaerobic endurance to anaerobic-aerobic endurance could be dependent upon muscle fibre composition. This may be illustrated by repeated isokinetic exercise at $180^{o} \cdot s^{-1}$ (Tesch, 1980).

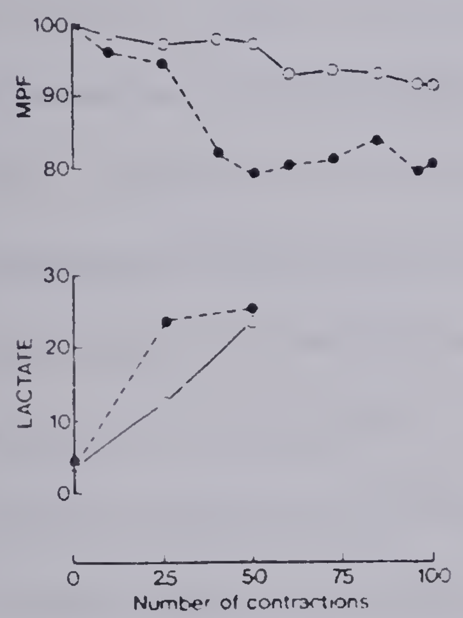

Figure 3. Changes for two individuals in mean power frequency (MPF) and muscle lactate concentration during repetition of 100 maximal knee extensions; subject GC (●): 54% FT fibres and subject GL (0): 34% FT fibres. (adapted from Tesch, 1980)

Subject GC (●)(54% type II fibres) shows a dramatic fall in mean power frequency after 25 contractions (approx. 30 s), coinciding with near maximal muscle lactate accumulation. In contrast, subject GL (0) (34% type II fibres) shows a decline after 50 contractions (approx. 60 s). The ability to maintain power from that point for a further period of time up to 2 min (100 contractions), has also been demonstrated by Thorstensson and Karlsson (1976). The decline in peak torque with 50 maximal knee extensor contractions has been positively correlated with

percentage of type II fibres (r = 0.88, Tesch et al. 1978) (r = 0.86, Thorstensson and Karlsson, 1976).

In repeated high-intensity exercise beyond 90 s, a reduction in lactate concentration during a short recovery phase is insignificant, although there is a significant recovery in CP and ATP stores (Saltin and Essen, 1971). This phase of exercise beyond 90 s is obtained during the 4th, 5th and 6th repeats of the RHIET (Figure 2).

The length of this phase may be dependent upon several factors; mode of activity, lactate accumulation, capillarization, muscle fibre type, or continuous or repeated exercise. During repeated high-intensity exercise, the work to rest ratio and duration of exercise phase, will affect the maintenance of performance or the onset of exhaustion (Saltin and Essen, 1971). However, it is proposed that this phase may be important for continuous high-intensity exercise up to 10 min duration. This is illustrated by the decline in running speed with time based on world records in running 100 m to 10,000 m (Figure 4). The 1980, 100 m world record is taken to be 100 per cent maximum velocity (Dyer, 1980a, 1980b). Per cent maximum velocity declines almost linearly to approximately 90 s and then begins to curve until levelling out at about 10 min. Thus, this phase comprises both anaerobic and aerobic components and is designated as anaerobic-aerobic endurance.

Aerobic Endurance - Factor I

The contribution of the aerobic system becomes more prominent than the anaerobic system at about 2 min (Astrand and Rodahl, 1977), and consequently is a determining factor in continuous exercise of greater than 2 min duration. It is well documented that endurance athletes have

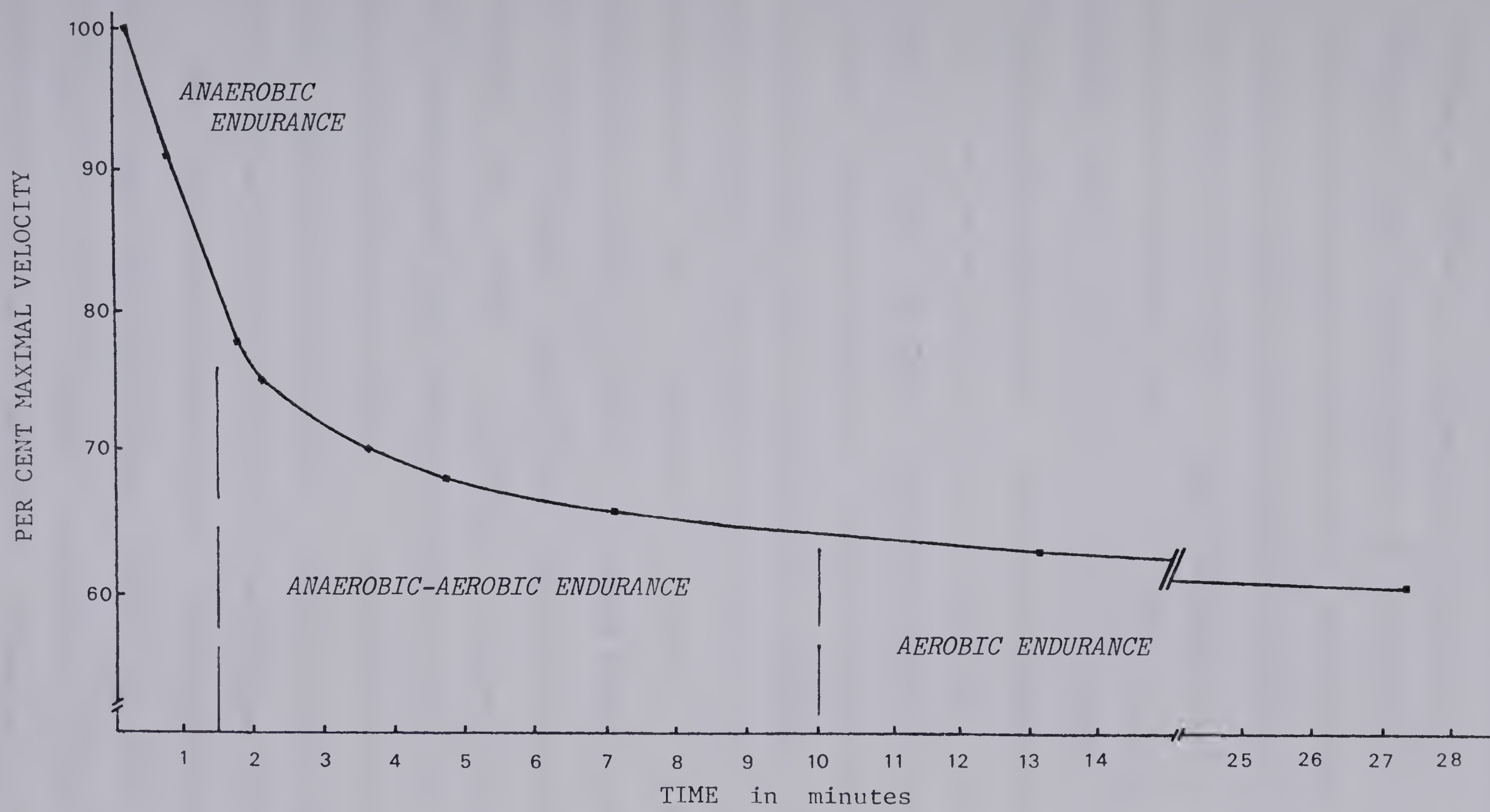

Figure 4: The decline in running speed with time based on world records in running 100m - 10,000m. The 1980 100m record is taken to be 100 per cent maximum velocity.

higher $\dot{V}O_2$ max values (Hermansen and Saltin, 1967; Costill et al. 1976) and are able to utilize a high fraction of their $\dot{V}O_2$ max during endurance performance (Davies and Thompson, 1979; Costill et al. 1973). Endurance athletes are also characterized by the predominance of type I fibres in recruited muscle groups (Costill et al. 1976) and high correlations have been reported between selected oxidative enzymes and $\dot{V}O_2$ max (Burke et al. 1977; Costill et al. 1976). A high correlation has been found between the muscle respiratory capacity of the vastus lateralis, as determined by pyruvate oxidation, and $\dot{V}O_2$ max ($r = 0.81$; $p < 0.001$) (Ivy et al. 1980a). They have also demonstrated a relationship between muscle respiratory capacity and the absolute work rate at which blood lactate accumulation begins ($r = 0.94$) (Ivy et al. 1980b) and suggest that the mitochondrial content of muscle is important in determining this work rate. Endurance training has been shown to stimulate the activities of mitochondrial enzymes (Hollozy, 1967; Orlander et al. 1977) as well mitochondrial volume (Morgan et al. 1971). A positive relationship ($r = 0.82$) has been demonstrated between $\dot{V}O_2$ max and the volume density of mitochondria from the vastus lateralis muscle in both trained and untrained men and women (Hoppeler et al. 1973). In contrast, it has recently been suggested that conventional heavy resistance training results in a reduction in the mitochondrial volume density in trained muscles (MacDougall et al. 1979). Significant correlations ($r = 0.95$) have also been demonstrated between fibre:capillary ratio and $\dot{V}O_2$ max (Ingjer, 1978).

The relationship between selected oxidative enzymes and $\dot{V}O_2$ max have not always been found to exist (Rusko et al. 1978). In training (Gollnick et al. 1972; Henriksson and Reitman, 1977) and in detraining studies (Henriksson and Reitman, 1977) the changes in the enzymes have not paralled the changes in $\dot{V}O_2$ max. Changes in performance have been

documented without changes in $\dot{V}O_2$ max (Daniels et al. 1978; Daniels, 1974; Ekblom, 1969) in trained athletes, whereas large changes in both $\dot{V}O_2$ max and performance have been reported in untrained subjects (Hickson et al. 1977; Davis et al. 1976) following endurance. Since oxidative enzymes, mitochondrial density, fibre to capillary ratio and proportion of type I fibres all reflect the aerobic capability of the athlete and since these physiological charateristics are critical for prolonged performance (beyond 10 min), this type of endurance is termed aerobic and corresponds to factor I in the factor analysis.

Physiological Model

The contribution to performance of the three factors outlined above, is illustrated in a physiological model of the continuum of endurance from short to prolonged duration exercise (Figure 5). The model represents the contribution to energy output of both aerobic and anaerobic processes in maximal efforts in events with large muscle group involvement (Astrand and Rodahl, 1977). The power of both processes will vary among individuals according to their training status, but it is suggested that as the time of exercise at maximal or near maximal intensity increases, the relative contributions of different physiological variables change. During the time period from 15 s to approximately 90 s, energy is derived predominantly from anaerobic sources and is consequently designated as "anaerobic endurance". From 90 s to 10 min, both anaerobic and aerobic contribute to the total energy requirement and is termed "anaerobic-aerobic endurance". In continuous exercise of greater than 10 min duration, aerobic energy sources supply 80 to 90 per cent of the required energy, and those physiological variables affecting "aerobic endurance" play a significant role in determining successful performance.

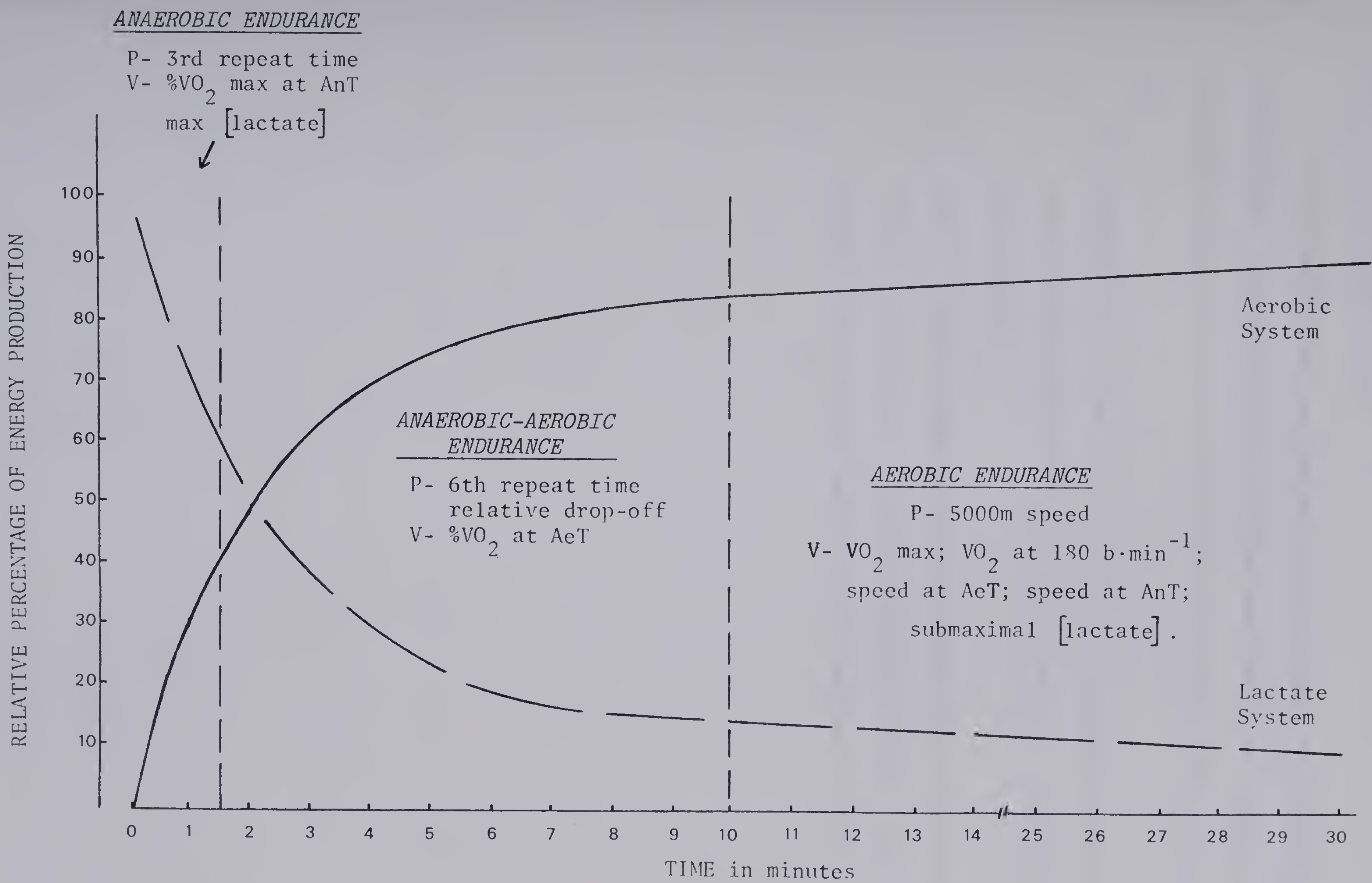

Figure 5: Physiological model representing the relative contribution in per cent of the total energy yield, from anaerobic and aerobic processes, during maximal effort up to 30 minutes duration (adapted from Astrand and Rodahl, 1977).
(P- performance variable; V- physiological variable)

Implications for Training

By integrating the time course of performance, the physiological determinants, the performance variables and the laboratory measures associated with each factor, the sports scientist, coach and athlete can:

1. Determine the appropriate demands of the activity and the physiological factors which either predict or contribute to the performance.
2. Assess both performance and functional status of the athlete.
3. Prescribe appropriate training regimens to alter the training status of the athlete based upon his endurance profile.

CONCLUSIONS

1. a) Factor analysis of the data revealed three physiological factors which are suggested to represent a continuum of endurance. The factors were designated to represent anaerobic endurance, anaerobic-aerobic endurance, and aerobic endurance.

   b) The laboratory variables which loaded highly on anaerobic endurance were % $\dot{V}O_2$ max at AnT and maximum lactate concentration. Per cent $\dot{V}O_2$ max at AeT loaded highly on anaerobic-aerobic endurance, and $\dot{V}O_2$ max, $\dot{V}O_2$ at 180 $b \cdot min^{-1}$, speed at AeT and AnT submaximal lactate concentration all loaded highly on aerobic endurance.

2. The laboratory measurement of speed at AnT was highly correlated with 5000 m speed performance and this performance speed may be predicted by use of the following regression equation:

   $$5000 \text{ m speed } (m \cdot min^{-1}) = -3.63 + 1.212 \cdot \text{speed at AnT } (m \cdot min^{-1})$$

   The regression equation for 5000 m speed prediction from % max heart rate at 215 $m \cdot min^{-1}$ is

   $$5000 \text{ m speed } (m \cdot min^{-1}) = 546.3 - 3.34 \cdot \% \text{ max HR at } 215 \ m \cdot min^{-1}$$

3. Selected variables from the repeated high-intensity endurance test (RHIET) had high loadings on the anaerobic endurance and anaerobic-aerobic endurance factors, and it is suggested that this test may be used as a field test of these factors.

4. Comparison of the five homogeneous groups and two mixed groups revealed that the endurance group was superior to all other groups in $\dot{V}O_2$ max (except hockey), speed at AnT and 5000 m speed, and superior to the mixed groups on two other variables, $\dot{V}O_2$ at 180 $b \cdot min^{-1}$ and speed at AeT, under the condition of running.

5. A physiological model representing a continuum of endurance is proposed which may permit a meaningful interpretation of the cardiovascular responses to specific sporting activities.

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APPENDIX A

REVIEW OF LITERATURE

This review is divided into the following sections: the relationship between maximal oxygen uptake ($\dot{V}O_2$ max) and performance; the relationship between histochemical and biochemical parameters and $\dot{V}O_2$ max; submaximal exercise lactic acid accumulation; anaerobic threshold and performance; predictive laboratory and field tests; and repeated high intensity endurance.

$\dot{V}O_2$ max and Performance

It has been suggested (Foster et al. 1977; Saltin and Astrand, 1967) that during prolonged physical work the performance capacity of the individual depends largely on his ability to take up, transport, and deliver oxygen to the working muscles. Maximal oxygen uptake ($\dot{V}O_2$ max) has been used extensively as a criterion of endurance performance. However, as mentioned by Costill (1973), $\dot{V}O_2$ max alone does not adequately predict a winning performance among runners with similar aerobic capacities.

Various authors (Costill et al. 1973; Forster et al. 1978) have presented evidence supporting the $\dot{V}O_2$ max-performance relationship. Correlation coefficients between $\dot{V}O_2$ max and 1, 2 and 6 miles of -0.84, -0.87 and -0.88 respectively (Forster et al. 1978) and -0.91 for 10 miles (Costill et al. 1973) lend support to the generalization that $\dot{V}O_2$ max is a major factor contributing to endurance performance. In these studies, heterogeneous samples in both performance times, abilities and $\dot{V}O_2$ max (50 to 72 $ml \cdot kg^{-1} \cdot min^{-1}$, Forster et al. 1978) were reported. However when more homogeneous samples have been assessed, this relationship diminishes

(Mayers and Gutin, 1979). They correlated $\dot{V}O_2$ max and best mile performances in a group of 8-11 year old boys consisting of 8 trained runners and 8 non-runners. When the elite runners and non-runners were grouped together, the correlation between $\dot{V}O_2$ max and the mile time was -0.89, but $\dot{V}O_2$ max within the elite group was unrelated to their best mile times (r = 0.06). Similarly, observations on a homogeneous group of marathon runners also showed $\dot{V}O_2$ max to be unrelated to performance (r = 0.08) (Costill et al. 1971; r = -0.12, Conley and Krahenbuhl, 1980). This demonstrates that although the correlation coefficient is a rather robust statistic, it is, nevertheless, susceptible to spurious inflation by a highly polarized sample (Guilford and Fructher, 1973).

In a particular sport, coaches have been able to identify specific performance variables, each of which carries a certain relative importance for that activity. Differentiation of a group of good and elite distance runners has recently been reported (Pollock et al. 1980) using discriminate function analysis. The elite runners were found to be on the upper end of a physiological capacity dimension reflected by $\dot{V}O_2$ max and $\dot{V}O_2$ at a submaximal speed. However, a second discriminate function differentiated elite marathon and middle-long distance runners whose high discriminant scores were associated with lower $\dot{V}O_2$ max and lactic acid values in combination with higher lean weight values. Consequently, this mathematical form of physiological analysis of the athlete demonstrated that within a relatively homogeneous group of elite athletes, the two groups were metabolically different.

Relationship Between Histochemical and Biochemical Parameters and $\dot{V}O_2$ max

The search for the physiological requirements for successful performance had been limited to metabolic and circulatory responses to exercise until the value of muscle biopsies became apparent with the studies of Bergstrom and Hultman (1966). Investigators have since constructed histochemical and biochemical profiles of trained and untrained subjects in order to find cellular characteristics that may identify superior performances particularly in homogeneous samples. Costill et al. (1973) suggested that future studies of the physiological prerequisite for successful distance running should be directed towards fibre distribution and metabolic qualities of the running musculature.

Indications from a study by Costill et al. (1976) examining the fibre composition and selected oxidative and glycolytic enzymes of female and male track athletes and untrained subjects seemed encouraging. Oxidative capacity as measured by SDH activity correlated with $\dot{V}O_2$ max ($r = 0.79$). However, scrutiny of the data reveals a polarized sample having high $\dot{V}O_2$ max-high SDH at one pole and untrained individuals, (low $\dot{V}O_2$ max, low SDH) at the other pole. Burke et al. (1977) testing competitive cyclists and untrained subjects reported $\dot{V}O_2$ max correlations with SDH ($r = 0.75$) and MDH activities ($r = 0.73$) in the skeletal muscle. This was in agreement with previous results between SDH and $\dot{V}O_2$ max shown by Gollnick et al. (1972, 1973) and again conducted with heterogeneous samples. Additional efforts to correlate $\dot{V}O_2$ max with other variables have revealed no significant relationships - % ST fibres ($r = 0.29$), LDH ($r = 0.05$) and phosphorylase ($r = 0.24$). Further studies found low correlations between SDH and $\dot{V}O_2$ max ($r = 0.23$) (Forster et al. 1978) and between % ST fibres and SDH activity ($r = 0.22$) (Costill et al. 1976). Thus, these studies have indicated a wide variation exists between bio-

chemical variables and $\dot{V}O_2$ max. Since $\dot{V}O_2$ max reflects many different parts of the oxygen transport system, alterations in selected components may not mirror changes in $\dot{V}O_2$ max.

Muscle biopsies from the recruited muscles of elite endurance athletes have been shown to consist predominatly of type I fibres (Gollnick et al. 1972; Costill et al. 1976). Positive relationships, r = 0.72 (Forsberg et al. 1976), r = 0.67 (Bergh et al. 1978), r = 0.56 (Rusko et al. 1978) have been demonstrated between % type I fibres and $\dot{V}O_2$ max when distinct athletic populations have been pooled. Specifically, Bergh et al. (1978) showed that the $\dot{V}O_2$ max varied from 50 to 80 ml/kg·min in subjects with equal distribution of type I and type II fibres and VO_2 max was as high as 60 $ml \cdot kg^{-1} \cdot min^{-1}$ in other subjects with from 30 to 75% ST fibres. These studies further illustrate the complex interrelationships between metabolic, histochemical, biochemical and endurance performance variables. These complex interrelationships would also suggest that endurance performance cannot be accurately predicted from muscle fibre composition alone. It has been suggested that $\dot{V}O_2$ max is a better predictor of competitive success than histochemical or biochemical muscle analysis (Burke et al. 1977) and that since it provides the best "indication of the level of trainedness" (Zatsiorskii et al. 1975), $\dot{V}O_2$ max has been the primary physiological test in assessing the training status for endurance performance.

Blood Lactate Concentration During Submaximal Exercise

It has been shown consistantly that physical training results in a decrease in blood lactate concentration at the same submaximal oxygen uptake (Ekblom et al. 1968; Fox et al. 1975; Williams et al. 1967). The accumulation of lactate in the blood at varying performance speeds

has been reported (Costill et al. 1973; Costill et al. 1971; Costill and Fox, 1969) and exhaustive exercise of a prolonged duration has been characterized by relatively low plasma lactate levels (Karlsson, 1971; Astrand et al. 1963). Costill et al. (1973) reported mean blood lactate concentrations after 10 minutes of running of 14.4 mg % at 215 m/min and 36.4 mg % at 268 m/min. However, at the latter speed, there was marked differences between the four subgroups with the accomplished runners (Group A) able to perform at the high speed with significantly less blood lactate. The accumulation of blood lactate is a function of oxygen consumed during exercise (Costill, 1970) expressed as a percentage of $\dot{V}O_2$ max. This was demonstrated in the Costill study by Group A which required 66% $\dot{V}O_2$ max compared to 91% by Group D to run at 268 m/min. As well, a correlation of 0.91 was shown between blood lactate accumulation after the 268 m/min run and the 10 mile performance time.

Anaerobic Threshold and Performance

The relationship between blood lactate accumulation at submaximal loads and performance has been implied by the occurrence of an "anaerobic threshold" at the running velocity at which lactate begins to accumulate in the plasma. More recently, the term anaerobic threshold has been expanded to include an aerobic-anaerobic transition between an "aerobic threshold" and an "anaerobic threshold" (Kindermann et al. 1979).

The anaerobic threshold (AT) was originally defined by Wasserman et al. (1973) as the level of work or oxygen consumption just below that at which metabolic acidosis and the associated changes in gas exchange occur. It has been used as an index of conditioning (Wyndham, 1974) because 1) endurance athletes have high AT values, which often occur at a high fraction of $\dot{V}O_2$ max (Astrand and Rodahl, 1977; MacDougall, 1977);

2) endurance athletes do not perform at $\dot{V}O_2$ max but at some fraction of $\dot{V}O_2$ max (Davies and Thompson, 1979).

Different incremental work tests have been used to detect AT. In bicycle ergometry, increases in intensity have varied from 90 $kpm \cdot min^{-1}$ each minute (Davis et al. 1979; Rusko et al. 1978; Wasserman et al. 1973) to 200 $kpm \cdot min^{-1}$ each min (Davis et al. 1976), and the duration of each intensity has varied from one minute (Davis et al. 1979) to three minutes (Weltman et al. 1978). Bicycle tests have been used in preference to treadmill running, because the imposed load is easily quantified and it is a non-specific mode of exercise for the general population. However, in one treadmill determination of AT (Kindermann et al. 1979) a constant grade of 5% was maintained throughout the exercise. The test was started at a running speed of 8 $km \cdot h^{-1}$ and was increased by 2 $km \cdot h^{-1}$ every 3 minutes.

The onset of AT (Wasserman et al. 1973) is characterized by an increase in $\dot{V}_E$ and the ventilatory equivalent for O_2 (i.e., $\dot{V}_E/\dot{V}O_2$) without an increase in the ventilatory equivalent for CO_2 (i.e., $\dot{V}_E/\dot{V}CO_2$) plus a non-linear rise in blood lactate from approximately 2 mmol/l. Davis et al. (1976) reported a correlation of 0.96 between the anaerobic threshold determined from gas exchange parameters and AT determined from repeated serial venous lactate samples.

There is evidence to suggest that there is a cellular basis to the AT. With increasing intensity of exercise, there is a greater recruitment of type IIa and probably type IIb fibres (Essen, 1977, 1978a, 1978b) depending upon the fibre type distribution of each athlete. Metabolic changes due to the greater recruitment of type II fibres leads to a greater production of lactate and the subsequent rise in $\dot{V}_E$ to compensate for the metabolic acidosis (Skinner and McLellan, 1980).

It has been suggested that a second abrupt increase in lactate at about 4 $mmol \cdot l^{-1}$ and continued steep rise until the termination of exercise be designated as the anaerobic threshold (AnT) and the gradual change in lactate concentration from 2 to 4 $mmol \cdot l^{-1}$ with increasing intensity of exercise be termed the aerobic-anaerobic transition phase (Mader et al. 1976; Kindermann et al. 1979; Skinner and McLellan, 1980).

Since the initial rise in lactate to approximately 2 $mmol \cdot l^{-1}$ results from an increased recruitment of type I fibres, the onset of the non-linear increase in $\dot{V}_E/\dot{V}O_2$ and steeper rise in lactate at 2 $mmol \cdot l^{-1}$ has been referred to as the aerobic threshold (AeT) (Kindermann et al. 1979; Skinner and McLellan, 1980). The term "aerobic threshold" seems more reasonable for describing the early rise because athletes have been shown to be able to run for 45-60 minutes on a treadmill at higher fractions of their $\dot{V}O_2$ max (80-85%) than would be possible if high rates of anaerobiosis were occurring.

Predictive and Field Tests

Predictive laboratory and field tests have been used to evaluate physical working capacity and, in some cases, correlated with $\dot{V}O_2$ max. The use of the Cooper 12 min run (1968) has been widely used since a correlation coefficient of 0.90 was reported in the original study and later studies (Doolittle and Bigbee, 1968; Burke, 1976) have found a similar correlation coefficient. A criticism of these tests however, together with other field tests, such as 600 yd, 800 yd, 1 and 2 mile runs is that the subjects need to be well motivated and have some judgment of pace. Furthermore, these tests were designed for the general population and assessment of a trained athlete by these methods is of very limited value.

In order to evaluate the trained athlete accurately and also attempt to exclude motivation from the tests, several investigators have developed alternative methods of determining performance capability. A test used in the Soviet Union (Waibaum and Tschekulyov, 1977) consists of determining running speed at a pulse rate of 170 $b \cdot min^{-1}$. It is claimed that research indicates that test results are closely correlated with $\dot{V}O_2$ max. Some investigators (Costill et al. 1971; Costill et al. 1973; Farrell et al. 1979) have used a treadmill velocity of 268 $m \cdot min^{-1}$ (6 min/mile) for 10 minutes duration and evaluated $\dot{V}O_2$ and heart rate response to that velocity. The race pace for 19.3 km was correlated -0.56 with $\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$) at 268 $m \cdot min^{-1}$ (Farrell et al. 1979) and % max heart rate at 268 $m \cdot min^{-1}$ was found to be a highly accurate predictor of running time in a 10 mile race (r - 0.98) (Costill et al. 1973). It may be suggested however, that these correlations were due to heterogeneous samples used in the studies (54-8-81.6 $ml \cdot kg^{-1} \cdot min^{-1}$, Costill et al. 1973) (46.3-73.7 $ml \cdot kg^{-1} \cdot min^{-1}$, Farrell et al. 1979). Other exercise physiologists (Houston et al. 1979) use as a criterion of endurance performance capability, the time to exhaustion in an intense submaximal run on the treadmill. The protocol requires the subjects to run at 16.1 $km \cdot h^{-1}$ at a grade calculated to demand 90% of $\dot{V}O_2$ max. Examination of the data reported for this type of test reveals wide intersubject variation between tests. Furthermore, motivation and pain tolerance may influence the performance time to a large degree.

Repeated High-Intensity Endurance

The ability to perform repeated bursts of high intensity exercise in such activities as basketball, volleyball, soccer and ice-hockey requires endurance. An extensive time-motion analysis of 8 varsity

ice-hockey players indicated that during each shift (approximately 90 s duration including stoppages), the playing heart rate averaged between 87-92% of the maximal value elicited during maximal treadmill exercise, and that during recovery (3-4 minutes) the heart rate rapidly declined but rarely decreased to below 125 $b \cdot min^{-1}$ (Green et al. 1978). Muscle biopsy analysis revealed extensive glycogen depletion in type II fibres for both forwards and defencemen, a feature normally found during running (Costill et al. 1971) at intensities below $\dot{V}O_2$ max (Green et al. 1978). Despite the intermittent pattern of play, the endurance nature of ice-hockey is further illustrated by a two-fold elevation in plasma FFA, suggesting that this aerobic substrate may be important in energy production and thus in sparing glycogen.

An on-ice hockey fitness test has been developed (Reed et al. 1980) to include both aerobic and anaerobic measures. The test consisted of 6 repeated bursts of maximum velocity skating for 300 ft (91.4 m). Repeats were 30 seconds apart which included work and rest time. Two measures, drop-off (the maximum difference between repeat times) and heart rate recovery were validated against off-ice tests such as $\dot{V}O_2$ max, peak lactate, mile run time, modified Margaria stair climb, and maximum heart rate recovery. The authors found correlations between the skate test and off-ice scores indicating that the drop-off score was more related to anaerobic fitness measures while heart rate recovery was related to aerobic fitness measures.

After considering this review of literature, it is evident that general relationships exist between laboratory, field and performance measures of endurance. Although two types of endurance have been described, laboratory measures have not been established that best reflect these components. It is hoped that this research will allow

a clearer understanding of the underlying physiological components of endurance so that accurate assessment of the training state can be carried out.

APPENDIX B

APPENDIX B-1: Intercorrelations among 11 dependent variables for all groups (n = 70)

	VARIABLE	1	2	3	4	5	6	7	8	9	10	11
1	$\dot{V}O_2$ max	1	0.6	0.49	-0.20	0.64	-0.27	-0.40	-0.10	-0.45	0.63	-0.39
2	$\dot{V}O_2$ max at 180 $b \cdot min^{-1}$		1	0.60	0.21	0.65	0.17	-0.29	-0.35	-0.24	0.55	-0.22
3	Speed at AeT			1	0.60	0.71	0.08	-0.29	-0.3	-0.21	0.64	-0.17
4	% $\dot{V}O_2$ max at AeT				1	0.12	0.36	0.20	-0.15	0.34	0.04	0.2
5	Speed at AnT					1	0.17	-0.45	-0.33	-0.36	0.87	-0.22
6	% $\dot{V}O_2$ max at AnT						1	0.06	-0.25	0.19	0.03	0.24
7	Relative Drop-Off							1	0.35	0.80	-0.44	0.11
8	Recovery HR at 2 min								1	0.13	-0.29	-0.33
9	6th Repeat time									1	-0.37	0.52
10	5000 m speed										1	-0.27
11	3rd Repeat time											1

APPENDIX B-2: Intercorrelations among 11 dependent variables for competitive athletes (n = 50)

	VARIABLES	1	2	3	4	5	6	7	8	9	10	11
1	$\dot{V}O_2$ max	1	0.44	0.42	-0.24	0.58	-0.27	-0.43	-0.09	-0.39	-0.66	-0.32
2	$\dot{V}O_2$ max at 180 $b \cdot min^{-1}$		1	0.56	0.31	0.65	0.25	-0.28	-0.42	-0.11	0.56	-0.08
3	Speed at AeT			1	0.58	0.70	0.07	-0.32	-0.23	-0.12	0.64	-0.11
4	% $\dot{V}O_2$ max at AeT				1	0.05	0.32	0.27	-0.09	0.43	-0.03	0.21
5	Speed at AnT					1	0.20	-0.49	-0.31	-0.29	0.88	-0.23
6	% $\dot{V}O_2$ max at AnT						1	0.07	-0.19	0.23	-0.02	0.21
7	Relative Drop-Off							1	0.39	0.74	-0.49	0.12
8	Recovery HR at 2 min								1	0.05	-0.24	-0.40
9	6th Repeat time									1	-0.32	0.58
10	5000 m speed										1	-0.29
11	3rd Repeat time											1

APPENDIX B-3: Intercorrelations among 13 dependent variables for a random sample from competitive and non-competitive groups (n = 33)

	VARIABLES	1	2	3	4	5	6	7	8	9	10	11	12	13
1	$\dot{V}O_2$ max	1	0.62	0.34	-0.25	0.53	-0.24	-0.31	0.05	-0.41	0.46	-0.48	0.47	-0.59
2	$\dot{V}O_2$ max at 180 $b \cdot min^{-1}$		1	0.57	0.23	0.7	0.36	-0.15	-0.25	-0.68	0.15	-0.15	0.52	-0.22
3	Speed at AeT			1	0.69	0.69	-0.16	-0.16	-0.06	-0.55	0.07	-0.10	0.59	-0.19
4	% $\dot{V}O_2$ max at AeT				1	0.25	0.57	0.14	-0.09	-0.19	-0.17	0.38	0.14	0.28
5	Speed at AnT					1	0.41	-0.40	-0.13	-0.70	0.12	-0.38	0.84	-0.28
6	% $\dot{V}O_2$ max at AnT						1	-0.10	-0.42	-0.44	-0.46	0.17	0.32	0.46
7	Relative Drop-Off							1	0.23	0.41	0.20	0.84	-0.44	0.12
8	Recovery HR at 2 min								1	0.33	0.31	0.13	-0.17	-0.45
9	Submax [lactate]									1	0.16	0.34	-0.68	0.13
10	Max [lactate]										1	-0.06	0.08	-0.46
11	6th Repeat time											1	-0.46	0.47
12	5000 m speed												1	-0.32
13	3rd Repeat time													1

APPENDIX C

APPENDIX C: Relative anaerobic threshold values (% $\dot{V}O_2$ max) obtained by Kindermann et al. (1979) (A) and in the present study (B)

A	Long-distance runners (n = 6)	89%
	Middle-distance runners (n = 9)	86%
	Cross-country skiers (n = 10)	85%
	400 m runners (n = 6)	84%
	Decathlon competitors (n = 10)	84%
B	Basketball players (n = 10)	89.9 ± 0.8 [a]
	Endurance athletes (n = 10)	88.6 ± 2.2
	Wrestlers (n = 10)	86.4 ± 3.2
	Volleyball players (n = 10)	85.5 ± 2.1
	Ice-Hockey players (n = 10)	82.7 ± 0.8

[a] mean ± SEM

APPENDIX D

APPENDIX D: Some published studies on aerobic threshold

% $\dot{V}O_2$ max	$\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$)	Author	Method of Determination
61.1(43.7 - 79.5)	50.4(44.0 - 59.6)	Williams et al., 1968	Bicycle ergometer; serial lactate
63.8(47.4 - 83.6)	48.8(39.6 - 62.1)	Davis et al., 1976	Bicycle ergometer; gas exchange
58.6(49.5 - 75.1)	52.9(42.7 - 65.2)		Treadmill; gas exchange
43.6 ± 3.7	34.8 ± 3.4 (Control)	Davis et al., 1979	Bicycle ergometer; gas exchange
49.4 ± 2.6	31.1 ± 2.4 (Pre-tr)		
57.0 ± 2.1	40.0 ± 2.3 (Post-tr)		
54.2(38.5 - 64.0)	50.6(38.0 - 64.7)	Ivy et al., 1980	Bicycle ergometer; lactate threshold
69.9(59.3 - 78.9)	61.7(46.3 - 73.7)	Farrell et al., 1979	Treadmill; onset of plasma lactate [a]
75.8	53.9	Green et al., 1979	Bicycle ergometer
71.0(54.8 - 84.7)	59.6(43.2 - 78.0)	Present study	Treadmill; gas exchange

[a] not considered as being synonymous with aerobic threshold

APPENDIX E

APPENDIX E-1a: Summary of the analysis of variance of age for the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	315.2	52.53	7.53	< 0.01
Error	63	439.5	6.98		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-1b: Scheffé test for comparing group means for age

Comparison			F
Mixed I	v	Basketball	27.56*
	v	Volleyball	23.37*
	v	Hockey	22.56*
	v	Wrestling	21.76*

Critical F (6, 63) required for significance at the 0.01 level in 18.60

* Significant at the 0.01 level

APPENDIX E-2a: Summary of the analysis of variance of height for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	2679.2	446.54	7.48	<0.01
Error	63	3759.8	59.68		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-2b: Scheffé test for comparing group means for height

Comparison			F
Basketball	v	Wrestling	36.93*
	v	Mixed II	18.88*
	v	Mixed I	16.41

Critical F (6, 63) required for significance at the 0.01 level is 18.60 and at the 0.05 level is 13.44

* Significant at the 0.01 level

APPENDIX E-3: Summary of the analysis of variance of weight for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	1039.8	173.30	2.31	>0.01
Error	63	4719.9	74.92		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-4a: Summary of the analysis of variance of heart rate at 215 $m \cdot min^{-1}$ for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	5714.9	952.49	8.10	< 0.01
Error	63	7409.9	117.62		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-4b: Scheffé test for comparing group means for heart rate at 215 $m \cdot min^{-1}$

Comparison			F
Endurance	v	Hockey	35.90*
	v	Mixed II	28.67*
	v	Volleyball	28.23*
	v	Mixed I	26.50*
	v	Wrestling	23.40*
	v	Basketball	17.95

Critical F (6, 63) required for significance at the 0.01 level is 18.60 and at the 0.05 level is 13.44

* Significant at the 0.01 level

APPENDIX E-5: Summary of the analysis of variance of $\dot{V}O_2$ at 215 $m \cdot min^{-1}$ for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	89.5	14.91	2.06	>0.05
Error	63	445.8	7.23		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-6a: Summary of the analysis of variance of $\dot{V}O_2$ max for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	1345.0	224.2	14.10	<0.01
Error	63	1001.6	15.90		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-6b: Scheffé test for comparing group means for $\dot{V}O_2$ max

Comparison			F
Endurance	v	Mixed I	62.87*
	v	Mixed II	43.37*
	v	Basketball	35.52*
	v	Volleyball	29.65*
	v	Wrestling	29.64*
Hockey	v	Mixed II	20.88*
Wrestling	v	Mixed I	19.43*

Critical F (6, 63) required for significance at the 0.01 level is 18.60

* Significant at the 0.01 level

APPENDIX E-7a: Summary of the analysis of variance of $\dot{V}O_2$ at 180 $b \cdot min^{-1}$ for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	1466.8	244.47	7.39	<0.01
Error	63	2083.2	33.07		

$F_{0.01}$ (6, 63), 3.10

$F_{0.01}$ (6, 63), 2.24

APPENDIX E-7b: Scheffé test for comparing group means for $\dot{V}O_2$ at 180 $b \cdot min^{-1}$

Comparison		F
Endurance	v Mixed I	37.28*
	v Mixed II	23.68*
	v Wrestling	15.84
	v Volleyball	15.10
	v Hockey	14.48

Critical F (6, 63) required for significance at the 0.01 level is 18.60 and at the 0.05 level is 13.44

* Significant at the 0.01 level

APPENDIX E-8a: Summary of the analysis of variance of speed at AeT for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	60.3	10.06	5.69	< 0.01
Error	63	111.3	1.77		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-8b: Scheffé test for comparing group means for speed at AeT

Comparison		F
Endurance	v Mixed I	24.1*
	v Mixed II	24.1*
	v Wrestling	13.80
	v Volleyball	13.80

Critical F (6, 63) required for significance at the 0.01 level is 18.60 and at the 0.05 level is 13.44

* Significant at the 0.01 level

APPENDIX E-9a: Summary of the analysis of variance of % $\dot{V}O_2$ at AeT for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	842.1	140.34	2.71	< 0.05
Error	63	3261.7	51.77		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-9b: Scheffé test for comparing group means for % $\dot{V}O_2$ max at AeT

Comparison	F
Basketball v Wrestling	13.85

Critical F (6, 63) required for significance at the 0.01 level is 18.60 and at the 0.05 level is 13.44

APPENDIX E-10a: Summary of the analysis of variance of speed at AnT for all activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	37.0	6.17	8.58	< 0.01
Error	63	45.3	0.72		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-10b: Scheffé test for comparing group means for speed at AnT

Comparison			F
Endurance	v	Mixed II	33.31*
	v	Mixed I	33.00*
	v	Hockey	30.33*
	v	Volleyball	30.04*
	v	Basketball	25.87*
	v	Wrestling	19.83*

Critical F (6, 63) required for significance at the 0.01 level is 18.60

* Significant at the 0.01 level

APPENDIX E-11: Summary of the analysis of variance of % $\dot{V}O_2$ max at AnT for all activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	499.4	83.2	2.30	< 0.05
Error	63	2279	36.2		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-12: Summary of the analysis of variance of the relative drop-off index for all activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	3.53	0.59	1.57	> 0.05
Error	63	23.49	0.37		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-13: Summary of the analysis of variance of recovery heart rate at 2 min following the repeated high-intensity endurance test for all activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	1997.6	332.93	2.02	> 0.05
Error	63	10382.2	164.80		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-14a: Summary of the analysis of variance of the first repeat time for all activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	2.78	0.46	3.99	< 0.01
Error	63	7.32	0.12		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-14b: Scheffé test for comparing group means for the first repeat time

Comparison	F
Volleyball v Basketball	15.52

Critical F (6, 63) required for significance at the 0.01 level is 18.60 and at the 0.05 level is 13.44

APPENDIX E-15a: Summary of the analysis of variance of the third repeat time for all activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	4.94	0.82	4.43	< 0.01
Error	63	11.69	0.18		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-15b: Scheffé test for comparing group means for the third repeating time

Comparison	F
Volleyball v Mixed I	12.53

Critical F (6, 63) required for significance at the 0.01 level is 13.44

APPENDIX E-16: Summary of the analysis of variance of the sixth repeat time for all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	4.19	0.70	2.49	< 0.05
Error	63	17.70	0.28		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-17a: Summary of the analysis of variance of 5000 m speed for all activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	92.31	15.38	14.71	< 0.01
Error	63	65.87	1.04		

$F_{0.01}$ (6, 63), 3.10

$F_{0.05}$ (6, 63), 2.24

APPENDIX E-17b: Scheffé test for comparing group means for 5000 m speed

Comparison		F
Endurance	v Volleyball	65.11*
	v Basketball	55.28*
	v Mixed II	51.13*
	v Mixed I	45.36*
	v Wrestling	39.66*
	v Hockey	39.96*

Critical F (6, 63) required for significance at the 0.01 level is 18.60

* Significant at the 0.01 level

APPENDIX E-18: Summary of the analysis of variance of the submaximal lactate concentrations for the volunteers with all the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	1766.0	294.3	2.35	>0.05
Error	26	3256.0	125.2		

$F_{0.01}$ (6, 26), 3.59

$F_{0.05}$ (6, 26), 2.47

APPENDIX E-19: Summary of the analysis of variance of the maximal lactate concentrations for the volunteer within the activity groups

Source of Variation	DF	SS	MS	F	P
Groups	6	5139.0	856.5	1.49	> 0.05
Error	26	14869.4	571.9		

$F_{0.01}$ (6, 63), 3.59

$F_{0.05}$ (6, 63), 2.47